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Method of breaking a brittle substrate

The invention relates to a method of breaking a substrate of brittle material, the method comprising the steps of providing a substrate of a brittle material, heating the substrate with a laser beam to create a heated spot on the substrate, moving the laser beam and the substrate with respect to each other to create a line of heated spots on the substrate, cooling the heated spots on the substrate by locally applying a cooling medium such that a micro-crack in the line of heated spots is propagated, and breaking the substrate along the line of micro-cracks by applying a force on the substrate.

Many products made from a brittle non-metallic material, e.g. glass and semi-conductor wafer materials, are formed by separating a piece, sheet, wafer, or panel into a number of smaller pieces of the desired size or sizes.

US-6,252,197 discloses a method for physically separating brittle substrates by forming a micro-crack in the substrate and controllingly propagating the micro-crack. An initial mechanical or laser scribing device forms a micro-crack in the substrate. A laser beam is applied onto the substrate on a separation line. A coolant stream comprising a mixture of pressurized gas and water intersects with the trailing edge of the laser beam. The temperature differential between the heat affected zone of the substrate and the coolant stream propagates the micro-crack. By applying a mechanical load the substrate is subsequently broken into smaller pieces along the separation line, which may be further processed e.g. to produce display devices.

It is a problem connected to this method that the mechanical load necessary to further open the induced surface cracks increases with time, i.e. the mechanical load is higher the longer the time elapsed between the moment of inducing micro-cracks and the final breaking of the substrate into smaller pieces. This is undesired since in a factory it is often not possible to immediately break the substrates after they have been treated with the laser beam. In that case the subsequent breaking of the substrate results in damage of edges and a lower production yield.

It is an object of the invention to provide a breaking process in which the breaking load remains constant over time after the initiation of micro-cracks. To this end the method according to the invention is characterized in that the cooling medium comprises an aqueous surfactant solution. The inventors have realized that the increase of the breaking load in the conventional process is due to locking or even healing of the micro-cracks. However, if the cooling medium comprises an aqueous surfactant solution the surfactants will connect to the broken siloxane bonds inside the micro-cracks. Recombination and healing of the broken siloxane bonds will not occur and the required breaking load will remain constant over time. Furthermore, the surfactants will change (i.e. lower) the surface energy of the cracks. Consequently, the cracks will be kept open and the load needed to open the cracks will be lowered.

The dependent claims describe advantageous embodiments of the invention.

These and other objects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

In the drawings:

Fig. 1 is a schematic view from above of an apparatus employing the method according the invention, and

Fig. 2 shows results of load measurements for various cooling media and various elapsed times.

The figures are not drawn to scale. In the figures, like reference numerals generally refer to like parts.

Fig. 1 is a schematic view from above of an apparatus employing the method according the invention. A spot 3 of a laser beam is focussed on substrate 1 of a brittle material, e.g. glass, crystalline silica, ceramics or compositions thereof. The energy contained in the laser spot 3 causes local heating of the substrate. A cooling medium from a nozzle 4 in the vicinity of the laser spot 3 (in most cases positioned behind the laser spot) cools the heated spot. This rapid temperature differential causes a thermal shock and causes a pre-existing micro-crack to propagate.

The substrate is moved with respect to the laser spot in a direction indicated by the arrow. Likewise, the laser beam may be moved with respect to the substrate in a direction opposite to the arrow. As a result of the relative movement the micro-crack is propagated along a separation line 2.

Next, the substrate 1 can be broken along the separation line 2 in a conventional way by exerting a mechanical load force to the substrate.

It has been observed that the mechanical load required to break the substrate depends on the amount of time elapsed between the formation of the micro-cracks and the moment of applying the mechanical load. Fig. 2 shows results of load measurements for various cooling media and various elapsed times. The data are provided with bars indicating the statistical spread on the measurements. Displayed is the required mechanical load (in Newton) for breaking the substrate in case of:

- a spray mixture of air and ethanol as cooling medium, 30;
- cooling by a spray mixture of air and water, and immediately followed by breaking, 40;
- cooling by a spray mixture of air and water, and breaking after 12 hours, 50;
- cooling by a spray mixture of air and an aqueous solution comprising 0.1% by weight of the surfactant cetyl trimethyl ammonium bromide (CTAB) and immediate breaking, 60;
- cooling by a spray mixture of air and an solution of water comprising 0.1% by weight of the surfactant cetyl trimethyl ammonium bromide (CTAB) and breaking after 15 hours, 70.

For reasons of comparison the mechanical load for the conventional mechanical scribe process is also indicated, 20.

From the data shown in Fig. 2 it can be concluded that the mechanical load is reduced by almost a factor of 2 if CTAB is used and that the reduction remains if breaking occurs after 15 hours. Good process yield was obtained when the glass plates were further processed and LCD panels were made from them.

CTAB is a compound belonging to the class of cationic surfactants, i.e. a surface active agent, a substance such as a detergent that reduces the surface tension of a liquid. Good results were also obtained with compounds belonging to the classes of non-ionic and anionic surfactants, such as octadecyl deca(ethyleenoxide) hydroxide or dodecylbenzene sulfonic acid sodium salt, respectively. All compounds have in common their capability of binding to the broken siloxane bonds ('dangling bonds') inside the micro-cracks.

Good results were obtained when the compounds were present in the aqueous solution in the range of 0.01 to 1 % by weight.

In summary, the invention relates to a method of breaking a substrate of brittle material, the method comprising the steps of providing a substrate 1 of a brittle material, heating the substrate with a laser beam 3 and creating a heated spot on the substrate, moving the laser beam and the substrate with respect to each other thus creating a line of heated spots

on the substrate 2, cooling the heated spots on the substrate by locally applying a cooling medium 4 behind the heated spots such that a micro-crack is propagated in the line of heated spots, breaking the substrate along the line of the propagated micro-cracks by applying a mechanical force on the substrate wherein, the cooling medium comprises an aqueous surfactant solution.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word "comprising" does not exclude the presence of other elements or steps than those listed in a claim. The word “a” or “an” preceding an element does not exclude the presence of a plurality of such elements.